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The OZI rule does not apply to Baryons

John Ellis
CERN – Geneva

Erwin Gabathuler
Physics Department, University of Liverpool
Liverpool, England

and

Marek Karliner* †
SLAC
Stanford, CA 94309, USA

ABSTRACT

Determinations of the π - N σ -term and the EMC measurement of deep inelastic polarized μp scattering and various theoretical arguments indicate that baryons contain a significant number of strange quark-antiquark pairs. Their presence gives rise to additional connected diagrams which evade the Okubo-Zweig-Iizuka (OZI) rule for meson-baryon couplings, and explain the apparent violation of the OZI rule seen in the reaction $\bar{p}p \rightarrow \phi\pi^+\pi^-$ as well as the process $pp \rightarrow pp\phi$ + pions, and the backward peak seen in $\bar{p}p \rightarrow K^+K^-$. We catalogue predictions, based on moments of deep inelastic structure functions, for the OZI-evading couplings to baryons of 0^{-+} , 0^{++} , and 2^{++} and other mesons. Processes where these predictions can be tested include backward meson production in π - N scattering as well as $\bar{p}p$ annihilation and pp scattering.

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† Address after Oct. 1, 1988: School of Physics and Astronomy, Tel-Aviv University, Tel-Aviv, Israel.

According to the Naive Quark Model (NQM)[1] the proton wave function contains just two u quarks and a d quark. This model gives a good general picture of hadron structure at large distances (small momentum transfers Q^2), while probes of shorter distance (larger Q^2) reveal more constituents, notably a sea of $\bar{q}q$ ($q = u, d, s$) pairs and gluons, qualitatively as expected on the basis of perturbative QCD.[2] However, there are now two experimental indications that these non-naïve constituents are present already at large distances (small Q^2). One indication comes from determinations of the π - N sigma term:[3]

$$\Sigma^{\pi N} \equiv \frac{1}{2}(m_u + m_d) \langle p | (\bar{u}u + \bar{d}d) | p \rangle \quad (1)$$

which is a factor of about 2 larger than the value expected from the Gell-Mann–Okubo mass formula and the assumption $\langle p | \bar{s}s | p \rangle = 0$, motivated by the NQM. The value (1) of $\Sigma^{\pi N}$ indicates instead that[4]

$$\frac{\langle p | \bar{s}s | p \rangle}{\langle p | \bar{u}u + \bar{d}d + \bar{s}s | p \rangle} \simeq 0.21 \quad (2)$$

A second indication comes from the recent EMC measurement of deep inelastic polarized μp scattering,[5] which indicates that[6]

$$\widetilde{\Delta s} = -0.24 \pm 0.07 \quad (3)$$

where $\langle p | \bar{s}\gamma_\mu\gamma_5 s | p \rangle \equiv 2s_\mu \cdot \widetilde{\Delta s}$: $\widetilde{\Delta s} \equiv \Delta s - (\alpha_s/2\pi)\Delta G$ [7, 8, 9] where Δs is the fraction of the proton spin carried by strange quarks and antiquarks, and ΔG is the fraction of the proton spin carried by gluons.*

In addition to these experimental facts, there are strong indications from Lattice Gauge Theory (LGT) that quark loops are important in baryon physics. Hadron spectrum calculations done in an approximation where quark loops are neglected (the so-called ‘quenched’ approximation) consistently obtain too big a ratio of m_p/m_ρ . More recently, attempts were made to compute the π - N sigma term in

* From now on, we shall drop the tildes on $\widetilde{\Delta s}$ etc. We note in passing that $\Delta G \simeq 0$ in one interpretation[10] of the Skyrme model.[11]

the quenched approximation.[12,13] These too, gave a value substantially smaller than the one obtained from π - N scattering.[†] Given that quark loops, i.e. non-valence quarks, are important, we would like to know whether non-valence s quarks are roughly as important as the non-valence u and d . One might have expected some suppression of s quark loops relative to those of u and d , because $m_s \gg m_{u,d}$. Phenomenologically, this suppression seems to be a moderate effect. When extracting $(m_u + m_d)/m_s$ from m_π^2/m_K^2 , [14] it is usually assumed that the vacuum expectation values of all three flavors are roughly of the same magnitude

$$\langle \bar{u}u \rangle_0 \sim \langle \bar{d}d \rangle_0 \sim \langle \bar{s}s \rangle_0 \quad (4)$$

QCD sum rules [16] and instanton liquid calculations [17] give

$$0.5 \lesssim \frac{\langle \bar{s}s \rangle_0}{\langle \bar{u}u \rangle_0} \lesssim 1 \quad (5)$$

These estimates are supported indirectly by the consistency of $(m_u + m_d)/m_s$ with the values of $m_{u,d,s}$ deduced from elsewhere, for example from baryon masses. Since $\langle p | \bar{s}s | p \rangle$ represents the perturbation of $\langle \bar{s}s \rangle_0$ in the neighborhood of the proton, one could expect $\langle p | \bar{s}s | p \rangle \sim \langle p | \bar{u}u, \bar{d}d | p \rangle$ if (5) holds.

Thus the proton wave function seems to contain a significant fraction of $\bar{s}s$ pairs, even when probed at large distances (small Q^2). Although a surprise for the NQM,[‡] the indications, (2),(3) of strange quarks in the proton are expected in models based on approximate chiral symmetry, i.e. light quarks: $m_{u,d,s} \ll \Lambda_{QCD}$. The Skyrme model, [11] which correctly reproduces the low-energy behavior of the QCD lagrangian in the limit of chiral symmetry, $m_{u,d,s} \rightarrow 0$, and a large number of colors, $N_c \rightarrow \infty$, predicts [4] 0.23 for the right-hand side of equation (2). In addition, there are other model-independent predictions for the strange content of

[†] See however ref.15 for a recent discussion of experimental uncertainties in determining the σ -term.

[‡] In the NQM language this means that the constituent quarks are objects which contain a substantial admixture of $\bar{s}s$ pairs. The traditional successes of the NQM, such as mass and magnetic moment calculations, remain unaffected by this fact. As we point out however, there are experimental phenomena where the presence of $\bar{s}s$ pairs does make a difference.

the proton, given by all chiral soliton theories of which the Skyrme model is the simplest representative. One such model-independent prediction is [18]

$$\Delta u = \frac{4}{7}g_A, \quad \Delta d = -\frac{3}{7}g_A, \quad \Delta s = -\frac{1}{7}g_A \quad (6)$$

With $g_A = 1.25$ taken from experiment,[◊] (6) yields

$$\Delta u = 0.71, \quad \Delta d = -0.54, \quad \Delta s = -0.18 \quad (7)$$

to be compared with the values [6]

$$\Delta u = 0.73 \pm 0.07, \quad \Delta d = -0.52 \pm 0.07, \quad \Delta s = -0.24 \pm 0.07 \quad (8)$$

extracted from experiment. [5]

The usual $1/N_c$ argument indicating that non-valence $\bar{q}q$ pairs are suppressed in mesons [19, 20] does not carry over immediately to baryon wave functions. [21] Quark-antiquark pairs are visualized as being generated by the splitting of gluons. In the $1/N_c$ expansion, baryons contain N_c quarks in a first approximation, and therefore the number of gluon exchange diagrams is enhanced by $\mathcal{O}(N_c^2)$ relative to their number in $\bar{q}q$ mesons. Color matching reduces this enhancement to $\mathcal{O}(N_c)$, a factor which carries over to the number of $\bar{q}q$ pairs relative to their abundance in mesons. Gluons are enhanced relative to $\bar{q}q$ pairs by $\mathcal{O}(N_c)$ in both mesons and baryons,[•] indicating that neglecting gluons may not be a good initial approximation to the baryon wave-function. Nevertheless, we still expect $\bar{q}q$ pairs to be $\mathcal{O}(N_c)$ more important in baryons than in mesons.

The fact that the proton wave function contains $\bar{s}s$ pairs even at large distances (low Q^2) implies that $\bar{s}s$ mesons can couple directly via connected diagrams to non-strange baryons, as in fig. 1a, thus evading the naïve form of the Okubo-Zweig-Iizuka (OZI) rule, [22] which implicitly assumes that such couplings can only

◊ We take g_A from experiment since while (6) is a *model-independent* prediction, the value of g_A is in general model-dependent.

• The same is also true in the vacuum, but this does not prevent the non-zero value of $\langle \bar{q}q \rangle_0$ from being important!

occur via disconnected diagrams, as in fig. 1b. Experimentally, the OZI rule is known to work well for meson-meson couplings, where it is theoretically justified by the $1/N_c$ expansion. [19, 20] However, as argued above, this justification does not extend to meson-nucleon couplings and, as we will see, there are several published experimental claims to see violations of the OZI rule for meson-nucleon couplings.

Most of the evidence for OZI evasion in meson-baryon couplings comes from $\bar{p}p$ annihilation both at rest and in flight. Several experiments have compared the rates for the OZI-forbidden process $\bar{p}p \rightarrow \phi \pi^+ \pi^-$ and the OZI-allowed process $\bar{p}p \rightarrow \omega \pi^+ \pi^-$. The general conclusion has been that $R_\phi^{\bar{p}} \equiv \sigma(\bar{p}p \rightarrow \phi \pi^+ \pi^-) / \sigma(\bar{p}p \rightarrow \omega \pi^+ \pi^-)$ is larger than the ratio $(7 \pm 2) \times 10^{-3}$ $[(1.5_{-0.9}^{+1.3}) \times 10^{-3}]$ expected on the basis of the departure from ideal mixing in the ϕ and ω mesons calculated using first-order $SU(3)$ breaking in a quadratic [linear] mass formula. For example, ref. 23 finds that

$$R_\phi^{\bar{p}} = (19 \pm 5) \times 10^{-3} \quad \text{for } p_{\bar{p}} = (0.70 \text{ to } 0.76) \text{ GeV} \quad (9)$$

after making a phase-space correction. Ref. 23 also finds that the c.m. angle distribution of the ϕ differs from that of the ω , which has a small amount of forward-backward peaking.[∇] Ref. 23 therefore claims that the OZI rule is violated in the reaction $\bar{p}p \rightarrow \phi \pi^+ \pi^-$, and finds an amplitude ratio

$$0.05 < \left| \frac{\sqrt{2}A(\bar{p}p \rightarrow \bar{s}s + X)}{A(\bar{p}p \rightarrow \bar{u}u + X) + A(\bar{p}p \rightarrow \bar{d}d + X)} \right| < 0.22 \quad (10)$$

that apparently violates the OZI rule, with the precise value of the ratio depending on the relative phase of the amplitudes. Other measurements give

$$R_\phi^{\bar{p}} = (15 \pm 3) \times 10^{-3}, [24] \quad (19_{-7}^{+5}) \times 10^{-3}, [25] \quad (30 \pm 7) \times 10^{-3}, [26] \quad (12_{-9}^{+5}) \times 10^{-3}, [25] \quad (11) \quad (11)$$

at $\bar{p}$ momenta of 0, 1.2, 2.3, 3.6 GeV, respectively, also indicating that the OZI rule appears to be violated (see also Ref. 27).

[∇] Later we will give a qualitative explanation of this feature.

Although fewer data are available, there is also evidence of an apparent violation of the OZI rule in the reaction $\bar{p}n \rightarrow \phi(\omega) + \pi^-$. The data of ref. 28 correspond to [29] $P(\bar{p}N \rightarrow \phi\pi^-) = (8.8 \pm 2.2) \times 10^{-4}$, whilst those of ref. 30 correspond [29] to $P(\bar{p}N \rightarrow \omega\pi^-) = (6.6 \pm 1.1) \times 10^{-3}$, leading to the estimate

$$R_{\phi}^{\bar{p}n} = \frac{\sigma(\phi\pi^-)}{\sigma(\omega\pi^-)} \sim 0.13 \quad (12)$$

This surprisingly large ratio should be checked and the related reactions $\bar{p}p \rightarrow \phi(\omega)\pi^0$ also measured, to confirm the apparently large deviation (12) from the OZI rule.

There is also evidence for a deviation from the naïve form of the OZI rule in $\bar{p}p$ annihilation to $f'(1525) + \text{pions}$, compared with $f(1275)$ or $A_2(1275) + \text{pions}$. Ref. 26 finds

$$R_{f'}^{\bar{p}} \equiv \frac{\sigma(f'\pi^+\pi^-)}{\sigma(f\pi^+\pi^-)} = (29_{-7}^{+11}) \times 10^{-3} \quad (13)$$

to be compared with the $(1 \text{ to } 2) \times 10^{-3}$ which would be expected from the ratio $\Gamma(f' \rightarrow \pi^+\pi^-)/\Gamma(f \rightarrow \pi^+\pi^-)$. Other experiments also find surprisingly many f' final states:

$$\begin{aligned} \frac{\sigma(\bar{p}p \rightarrow f'\pi^+\pi^-)}{\sigma(\bar{p}p \rightarrow f\pi^+\pi^-)} &\sim 0.43, \quad [31] \\ \frac{\sigma(\bar{p}p \rightarrow f'\pi^0)}{\sigma(\bar{p}p \rightarrow (f + A_2)\pi^0)} &\sim 0.064, \quad [32] \\ \frac{\sigma(\bar{p}p \rightarrow f'\pi^0)}{\sigma(\bar{p}p \rightarrow A_2^\mp\pi^\pm)} &\sim 8.6 \times 10^{-3} \quad [32] \end{aligned} \quad (14)$$

indicating that the naïve OZI rule is also inapplicable to tensor meson couplings to baryons, possibly even to a greater extent than for vector mesons.

On the other hand, the ratio of forward $\pi^-p \rightarrow Vn$ cross-sections, $R_{\phi}^{\pi} = \sigma(\pi^-p \rightarrow \phi n)/\sigma(\pi^-p \rightarrow \omega n) = (3.2 \pm 0.4) \times 10^{-3}$ at $p_{\pi}=6 \text{ GeV}$, [33] is in agreement

with the OZI rule and the expected deviation from ideal mixing.[†] Moreover, the natural spin-parity exchange (NEX) amplitudes for $\pi^- p \rightarrow \phi n$ and ωn have similar t -dependences, suggesting that the NEX meson-meson-Reggeon vertices obey the OZI rule, as expected. However, at lower energies [36, 37, 38] there is a relative enhancement of R_ϕ^π since $\sigma(\pi^- p \rightarrow \phi n)$ falls more rapidly with p_π than does $\sigma(\pi^- p \rightarrow \omega n)$, and ϕ production has a broader t -distribution than does ω production. These observations are consistent with the appearance at lower energies of subleading pieces in the amplitude which evade the OZI rule and could be associated with baryonic vertices.

More evidence against the naïve OZI rule comes from $pp \rightarrow pp(\phi \text{ or } \omega)n\pi$ reactions. One experiment at $p_p = 24$ GeV finds [39]

$$R_{\phi(\pi^+\pi^-)^n}^p \equiv \frac{\sigma(pp \rightarrow pp\phi, pp\phi(\pi^+\pi^-), pp\phi(\pi^+\pi^-)^2)}{\sigma(pp \rightarrow pp\omega, pp\omega(\pi^+\pi^-), pp\omega(\pi^+\pi^-)^2)} = (19 \pm 7) \times 10^{-3} \quad (15)$$

while another experiment at $p_p=10$ GeV finds [34]

$$R_\phi^p = \frac{\sigma(pp \rightarrow pp\phi)}{\sigma(pp \rightarrow pp\omega)} = (20 \pm 9 \pm 8) \times 10^{-3} \quad (16)$$

The former experiment [39] indeed claims on the basis of a comparison between the ratio (16) and the corresponding ratio for incident pions that “... ϕ is produced also from strange quarks in the incident particle, with protons containing more $\bar{s}s$ pairs than pions”.

In addition to the above pieces of evidence that the naïve OZI rule is violated in meson-baryon couplings, there is another indication from $\bar{p}p$ annihilation that baryons contain significant numbers of $\bar{s}s$ pairs. A backward peak has been observed [40] in the reaction $\bar{p}p \rightarrow K^+K^-$ at $p_{\bar{p}} \sim 0.5$ GeV. It is not present at lower momenta, where only a few direct channel partial waves contribute, and disappears at higher momenta where non-exotic t -channel exchanges are expected

[†] There are also measurements of $R_{\pi\phi}^\pi \equiv \sigma(\pi^- p \rightarrow \pi\phi p)/\sigma(\pi^- p \rightarrow \pi\omega p) = (6 \pm 3 \pm 2) \times 10^{-3}$ at $p_\pi = 10$ GeV, [34] and $R_{3\pi\phi}^\pi \equiv \sigma(\pi^- p \rightarrow \pi^+\pi^-\pi^-\phi p)/\sigma(\pi^- p \rightarrow \pi^+\pi^-\pi^-\omega p) = 5_{-2}^{+5} \times 10^{-3}$ at $p_\pi = 19$ GeV [45] which are also in agreement with the OZI rule.

to dominate. The appearance of this backward peak is *prima facie* evidence of a direct $p \rightarrow K^-$ coupling, which is forbidden in the NQM model, where $p = |uud\rangle$, $K = |s\bar{u}\rangle$, but is allowed if the proton wavefunction contains $\bar{s}s$ pairs, as seen in fig. 2a. This coupling is related by crossing to the exotic channel $K^+p \rightarrow Z^*$. Despite the recent appearance of two partial wave analyses [41] agreeing on the presence of a P_{13} resonance in K^+p scattering, the Particle Data Group [42] does not recognize the evidence for any Z^* resonance. Instead, it comments that “the results permit no definite conclusion – the same story heard for 15 years” and “the general prejudice against baryons not made of three quarks (...) make it likely that it will be another 15 years before the issue is decided”. However, exotic states such as the Z^* are predicted by the Skyrme model. [43] Since their existence goes against the general prejudice so well reflected by ref. 42, they have historically been regarded as rather embarrassing for the model. Perhaps the boot should now be on other foot.

After this review of the experimental indications that the naïve OZI rule is indeed inapplicable to baryons, we now make some quantitative estimates of OZI-evading meson-baryon couplings.

0^{-+} mesons: Their couplings to baryons are related by PCAC and the Goldberger-Treiman relation to the baryonic matrix elements of axial currents. We know from experiment [5] and the Skyrme [18] model that $\Delta s \neq 0$ (see eq. (3)) (a *prima facie* breach of the naïve OZI rule) and $\Delta u + \Delta d + \Delta s \simeq 0$ [see eq.(8)]. We therefore predict [18] that

$$g_{\eta_0 \bar{p} p} \simeq 0 \quad (17)$$

where $\eta_{0(8)}$ is the $SU(3)$ -singlet (-octet) pseudoscalar meson. This result can be derived directly in the Skyrme model which also predicts the vanishing of all other η_0 couplings to baryonic matter, such as $g_{\eta_0 \bar{p} N^*}$, $g_{\eta_0 N^* N^*}$. We expect that $g_{\eta_0 \bar{p} p} \simeq 0$ in the limit of chiral symmetry: $m_{u,d,s} = 0$ and a large number of colors. Some corrections to this idealized prediction can be estimated. Pseudoscalar meson loop corrections, which are of next-to-leading order in $1/N_c$, do not alter the predictions that $\Delta u + \Delta d + \Delta s = 0$ and $g_{\eta_0 \bar{p} p} = 0$, but possible other $1/N_c$ corrections cannot be excluded at this time. Chiral symmetry breaking may explain why the physical pseudoscalar η and η' are mixtures of η_8 and η_0 with a mixing angle θ of 10° to

20°. Taking, for example, $\theta \simeq 14^\circ$ as suggested by a first-order analysis of chiral symmetry breaking, we find [18]

$$\frac{g_{\eta' \bar{p}p}}{g_{\eta \bar{p}p}} \simeq \tan \theta \simeq 0.25 \quad (18)$$

which is not in conflict with experiment, but should not be taken as a very reliable estimate.

1^{--} mesons: These mesons' couplings are usually related to the zero-momentum-transfer ($Q^2 = 0$) matrix elements of vector currents by the Vector Meson Dominance (VMD) hypothesis. [44] We know that $\langle p | \bar{s} \gamma_\mu s | p \rangle = 0$ at $Q^2 = 0$, because it measures the net strangeness of the proton

$$\#(s) - \#\bar{s} \equiv \int_0^1 dx [s(x) - \bar{s}(x)] = 0 \quad (19)$$

(where $s(x)$ and $\bar{s}(x)$ are parton densities for strange quarks and anti-quarks) which vanishes because of the proton's net quantum numbers. It follows from (19) and VMD that

$$g_{\phi \bar{p}p} = 0 \quad (20)$$

Therefore, exceptionally, the OZI rule works for this and other *elastic* ϕ -baryon couplings. However, naïve VMD is not directly applicable to inelastic form factors and therefore in general one could expect that the *inelastic* coupling

$$g_{\phi \bar{p}N^*} \neq 0 \quad (21)$$

for any baryon resonance N^* . The vanishing of $g_{\phi \bar{p}p}$ (20), whereas $g_{\omega \bar{p}p} \neq 0$, indicates that the angular distribution of the ϕ in $\bar{p}p \rightarrow \phi \pi^+ \pi^-$ should not be peaked forward-backward in the same way as the ω in $\bar{p}p \rightarrow \omega \pi^+ \pi^-$ (as seen by experiment [23]). However, since inelastic couplings (21) do not vanish in general, we would expect $R_\phi^{\bar{p}} \equiv \sigma(\bar{p}p \rightarrow \phi \pi^+ \pi^-) / \sigma(\bar{p}p \rightarrow \omega \pi^+ \pi^-)$ to be larger than the OZI expectation of a few $\times 10^{-3}$ (as also seen by experiment (9),(11)[23,24,25,26]). A sample diagram enhancing $R_\phi^{\bar{p}}$ is shown in fig. 2b. The value of $R_{\phi(\pi^+\pi^-)}^p$ should also be

enhanced (as observed (15),(16)^[39]), whereas we would expect $R_{\phi(\pi^+\pi^-)n}^\pi$ to be given by the OZI rule for ϕ mesons in the beam fragmentation region (as observed)^[45], but larger in the target fragmentation region (for which data are not available). The nonzero inelastic vertices $g_{\phi\bar{p}N^*}$ may also explain why $\sigma(\pi^-p \rightarrow \phi n)/\sigma(\pi^-p \rightarrow \omega n)$ is seen to exceed the OZI expectation at low energies. [36,37] On the other hand, since the η_0 should not couple even inelastically to baryons, we expect no such low energy enhancement for $\sigma(\pi^-p \rightarrow \eta' n)/\sigma(\pi^-p \rightarrow \eta n)$ (as seen by experiment^[46,47]).

0^{++} mesons: The NQM assignments of the known scalars are obscure, and the theoretical possibility exists of substantial mixing between $\bar{q}q$, $\bar{q}q\bar{q}q$ and gluonium states. In principle, by analogy with VMD, one can use Scalar Meson Dominance (SMD) of the $Q^2 = 0$ matrix elements of $\bar{s}s$, $\bar{u}u$ and $\bar{d}d$ densities between protons and the π - N σ -term information (2) or the Skyrme model to infer that

$$\frac{g_{0^{++'}}}{g_{0^+}} = \begin{cases} 0.38 & (\sigma\text{-term}) \\ \frac{7\sqrt{2}}{23} \simeq 0.43 & (\text{Skyrme}) \end{cases} \quad (22)$$

where here and subsequently we denote the $\bar{s}s$ member of a meson nonet by a prime ($0^{++'}$, $1^{++'}$, etc.) while the $I = 0$ non-strange member is unprimed. However, the above-mentioned phenomenological uncertainties seem to preclude any clear test of this potentially large deviation from the naïve OZI rule.

1^{++} mesons: The analogue of the previous PCAC, VMD and SMD hypotheses would be to suppose (AMD) that axial mesons dominate the $Q^2 = 0$ matrix elements of the transverse components of the corresponding axial currents. The previous analysis [18] of axial current matrix elements combined with AMD suggests that

$$g_{1^{++'}\bar{p}p} = -\sqrt{2}g_{1^{++}\bar{p}p} \quad (23)$$

Even if this result is correct, its implications for the physical isoscalar D and E mesons are unclear, since their mixing pattern is not known. We quote below predictions based on (23) for different possible mixing patterns:

$$\frac{g_{E\bar{p}p}}{g_{D\bar{p}p}} = \begin{cases} 0 & (\text{singlet/octet}) \\ -\sqrt{2} & (\text{ideal mixing}) \\ -0.68 & (\text{ref. 48}) \end{cases} \quad (24)$$

It should be noted that the E meson first seen in $\bar{p}p$ annihilation was identified as

O^{-+} , and can probably be identified with the ι seen subsequently in radiative J/ψ decay. The fact that the D meson has been seen in $\bar{p}p$ annihilation but not the 1^{++} E meson might be taken as evidence against ideal mixing, if the predictions (24) are to be believed. At least the possibility of apparently OZI-violating couplings to baryons should not be neglected in future D and E phenomenology.

2^{++} mesons: For these and higher-spin mesons we propose a weakened form of the previous meson dominance hypotheses, namely that the ratios of spin- J $\bar{s}s(J')$, $I = 0$ $(\bar{u}u + \bar{d}d)/\sqrt{2}$ (J) and $I = 1$ $(\bar{u}u - \bar{d}d)/\sqrt{2}$ (J_1) meson couplings to baryons are equal to the ratios of the corresponding matrix elements of local spin- J operators at $Q^2 = 0$, e.g. $\langle p | \bar{s} \gamma_\mu \vec{D}_\nu s | p \rangle$ etc. for spin 2. These matrix elements are in turn related in the parton model to the $(J-1)$ -th moments of parton distributions in baryons:

$$\begin{aligned}
g_{J'\bar{p}p} : g_{J\bar{p}p} : g_{J_1\bar{p}p} = \\
\int_0^1 dx x^{J-1} \left(s(x) + (-1)^J \bar{s}(x) \right) : \\
\int_0^1 dx x^{J-1} \left[(u(x) + d(x)) + (-1)^J (\bar{u}(x) + \bar{d}(x)) \right] / \sqrt{2} : \\
\int_0^1 dx x^{J-1} \left[(u(x) - d(x)) + (-1)^J (\bar{u}(x) - \bar{d}(x)) \right] / \sqrt{2}
\end{aligned} \tag{25}$$

This Ansatz enables us to calculate $g_{f'\bar{p}p}/g_{f\bar{p}p}$ and $g_{A_2\bar{p}p}/g_{f\bar{p}p}$, given an appropriate set of deep inelastic structure functions. The Table shows values of $g_{f'\bar{p}p}/g_{f\bar{p}p}$ and $g_{A_2\bar{p}p}/g_{f\bar{p}p}$ calculated using the Duke and Owens[49] and Eichten, Hinchliffe, Lane and Quigg[50] parton distributions. We see that

$$\frac{g_{f'\bar{p}p}}{g_{f\bar{p}p}} \simeq 0.10 \pm 0.05, \quad \frac{g_{A_2\bar{p}p}}{g_{f\bar{p}p}} \simeq 0.32 \pm 0.08 \tag{26}$$

These predictions could be tested in $\bar{p}p$ annihilation, backwards meson production in πp collisions, and in pp collisions. Because the elastic $f'\bar{p}p$ coupling does not

vanish, unlike the elastic $\phi\bar{p}p$ coupling, there might be forward-backward peaking in $\bar{p}p \rightarrow f'\pi^+\pi^-$, similar to that expected for $\bar{p}p \rightarrow f\pi^+\pi^-$ and that seen in $\bar{p}p \rightarrow \omega\pi^+\pi^-$ (but not $\bar{p}p \rightarrow \phi\pi^+\pi^-$). Certainly we expect $R_{f'}^{\bar{p}}$ to be larger than expected from the OZI rule (as seen by experiment ^[26,31,32]).

3⁻⁻ mesons: According to the general formula (25), their couplings to baryons should be proportional to the moments $\int_0^1 dx x^2 (s(x) - \bar{s}(x))$ etc... It is normally assumed that the s and $\bar{s}$ distributions have the same shape, but there is no rigorous reason why this should be so: all one knows is that $\int_0^1 dx s(x) = \int_0^1 dx \bar{s}(x)$. In principle, a difference between $s(x)$ and $\bar{s}(x)$ could be seen in the neutrino-production of charm, but in practice they are difficult to disentangle with sufficient accuracy from the competing $d(x) [\bar{d}(x)]$ distributions.

4⁺⁺ mesons: Predictions for their couplings to baryons are also given in the Table. However, since only one $I=0$ 4⁺⁺ meson has been identified so far, [42] namely the $h(2030)$ which is presumably predominantly non-strange, it is not yet possible to test the predicted magnitude of the OZI-violating 4⁺⁺-baryon coupling.

We conclude this paper with a few comments on gluonium searches in processes with incident baryons. The fact that meson couplings to baryons violate the OZI rule means that the observation of a resonance in an OZI-forbidden channel does not necessarily mean that it is a gluonium state. It could be an excited $\bar{s}s$ state. This caution applies in particular to the $\phi\phi$ resonances reported in ref. 51.

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Table

Values of $g_{J'\bar{p}p}/g_{J\bar{p}p}$ and $g_{J_1\bar{p}p}/g_{J\bar{p}p}$ for $J = 2$ and $J = 4$, calculated using eq. (25) and the distributions of refs. 49 and 50 with $Q^2 = 6 \text{ GeV}^2$ and $\Lambda = 200 \text{ MeV}$. These numbers do not change qualitatively if Q^2 is taken as 10 GeV^2 , or if Λ is increased by between 100 and 200 MeV.

Distribution	$g_{f'\bar{p}p}/g_{f\bar{p}p}$	$g_{A_2\bar{p}p}/g_{f\bar{p}p}$	$g_{4'\bar{p}p}/g_{4\bar{p}p}$	$g_{4_1\bar{p}p}/g_{4\bar{p}p}$
D&O [49]	0.145	0.249	0.027	0.451
EHLQ [50]	0.057	0.391	0.010	0.557

FIGURE CAPTIONS

1. (a) A connected diagram coupling a $\bar{s}s$ meson (e.g. ϕ, f') to a non-strange baryon via non-valence $\bar{s}s$ quarks, thereby evading the OZI rule. (b) A disconnected OZI-forbidden diagram contributing to the same vertex.
2. (a) A connected diagram contributing to a backward peak in the region $\bar{p}p \rightarrow K^- K^+$ via non-valence $\bar{s}s$ quarks. (b) A connected diagram contributing to the reaction $\bar{p}p \rightarrow (\phi \text{ or } f')\pi^+\pi^-$.

FIG. 1

(a)

(b)

FIG. 2